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The effect of potential heap construction methods on column bioleaching of copper flotation tailings containing high levels of fines by mixed cultures

Xiaodong Hao, Yili Liang *, Huaqun Yin, Liyuan Ma, Yunhua Xiao, Yazi Liu, Guanzhou Qiu, Xueduan Liu *

School of Minerals Processing and Bioengineering, Central South University, Changsha, China
Key Laboratory of Biometallurgy, Ministry of Education, Changsha, China

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ABSTRACT

It is known that excess fines may reduce heap permeability and block channelings of leachate flow in heap bioleaching operation, and further cause low metal recovery. The purpose of this investigation was to compare the effects of three potential heap construction methods including layered heap construction method (Method A), agglomerate heap construction method (Method B) and pelletized sintering heap construction method (Method C) of copper flotation tailings on column bioleaching behaviors. In the three heap construction methods, the tailings copper extractions achieved 54.61%, 60.09% and 43.93%, respectively, in Method A, B and C on day 83. Copper extraction of Method B reached maximum. In addition, compositions and structures of microbial communities were examined using Illumina Miseq sequencing technology based on 16S rRNA amplification. *Acidithiobacillus*, *Leptospirillum* and *Ferroplasma* were main microorganisms in three heap construction methods. Detrended correspondence analysis showed that Method C had little effect on microbial communities. These studies revealed the influence of different heap construction methods on leaching behaviors and microbial dynamics, which will facilitate the bioleaching of fine-grained ores.

1. Introduction

Due to the continuous exploitation and consumption of valuable mineral resources, metal recovery from the tailings and low-grade ores becomes increasingly important. Traditional pyrometallurgy grows less desirable for tailings or low-grade ores on account of the stringent requirement of environmental protection and the inefficient use of resources and energies (Brierley, 2008; Watling, 2006). However, bioleaching, as an emerging and frontier technology, has been applied into the extraction of copper, cobalt, nickel, zinc and uranium from low grade sulfide minerals.

The megaton flotation tailings used in this study were from Lualo in Zambia. It has high fines content (the proportion was 48% of <75 μm), but a low clay content. As the leachate percolates through the heap containing high levels of fines, the raffinate can cause migration of fine particles and clog the natural flow channels within the ore bed, which form impermeable layers inside the heap. The impermeable layers would affect the transfer of oxygen and carbon dioxide and eventually result in low metal recovery efficiency. Thus, heap construction methods and raw ores pretreatment were the principal factors in bio-heap construction.

Many methods were utilized to resolve this problem. Garcia and Jorgensen (1997) had indicated that the ores should be determined for agglomeration supposing that the percentage of fines smaller than 75 μm was >15%. Many studies had applied laboratorial practice of agglomeration with many polymeric binders such as polyacrylamide, stucco, bentonite et al. into metal recovery in heap leaching operations and gained high metal leaching rates (Bouffard, 2008; Kodali et al., 2011; Lewandowski and Kawatra, 2009). In the 1980s, Sociedad Mineral Pudahuel originally applied the thin-layer leaching concept into copper oxides and copper sulfides extractions in the copper industry, which contributed to the remarkable expansion of the heap bioleaching, solvent extraction, and electrowinning process in South America. Although above methods had advanced the industrial practice of copper heap leaching operations, the effects of heap construction method and ores pretreatment on metal recovery were still unclear.

Understanding the microbial structure and succession was also important to advance commercial bioheap leaching operations

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* Corresponding author at: School of Minerals Processing and Bioengineering, Central South University, Changsha, China.

E-mail addresses: liangyili@hotmail.com (Y. Liang), xueduanliucsu@163.com (X. Liu).

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(Brierley, 2001; Rawlings, 2002). Brierley and Brierley (2013) showed that potential interactions among microbial community dynamics were the keys to improve bioleaching and biooxidation. In most cases, the investigation of microbial populations was mainly focused on free microorganisms in the leachate. However, attached microorganisms on the mineral surfaces also played undeniable roles on bioleaching (Gautier et al., 2008). Therefore, it was necessary to monitor the shifts of attached microorganisms on the mineral surfaces during tailings bioleaching. Although many nucleic acid-based molecular methods (e.g., RFLP, SSCP, DGGE) had been applied to determine microbial structures in bioleaching environments, high-throughput and high-resolution detection methods could offer a rapid and simple method to quantify the microbial communities (Orgiazzi et al., 2013).

Therefore, in this paper, three potential heap construction methods were carried out to investigate the column bioleaching of fine-grained flotation tailings by mixed cultures. This paper attempts to detail the effects of heap construction methods and raw ore pretreatments on leaching behaviors and microbial dynamics of fines bioleaching, and the data presented in this study would be helpful in the industrial applications of copper industry.

2. Materials and methods

2.1. Minerals components

The copper flotation tailings in this test were obtained from tailings dam in Lualo, Zambia. The percentages of different particle size distributions of tailings were 48% (<75 μm), 43% (75–150 μm) and 9% (150–270 μm), respectively. Copper phase analysis showed 29.47% free copper oxide, 6.32% combined copper oxide, 28.95% secondary copper sulfide and 35.26% primary copper sulfide. The main chemical composition of tailings was (w/w) 0.19% Cu, 19.73% Fe, 2.25% S, 3.27% Ca, 1.25% Na, 4.6% Al and 1.4% K. Whole ore substrate used in this study was obtained from the Yulong copper mine in Xizang of China, which contains (w/w) 2.75% Cu, 16.64% Fe, 17.41% S and 10.47% Al.

2.2. Column bioreactor configuration and heap construction methods

50 cm high column made of 0.5 cm thickness plexiglass with the internal diameter of 7 cm were used in this study. A plexiglass support plate with numerous 0.3 cm holes was placed at the bottom of the column. The leaching solution passed through the ore samples by gravity and recirculated through a side loop with a peristaltic pump (Fig. 1).

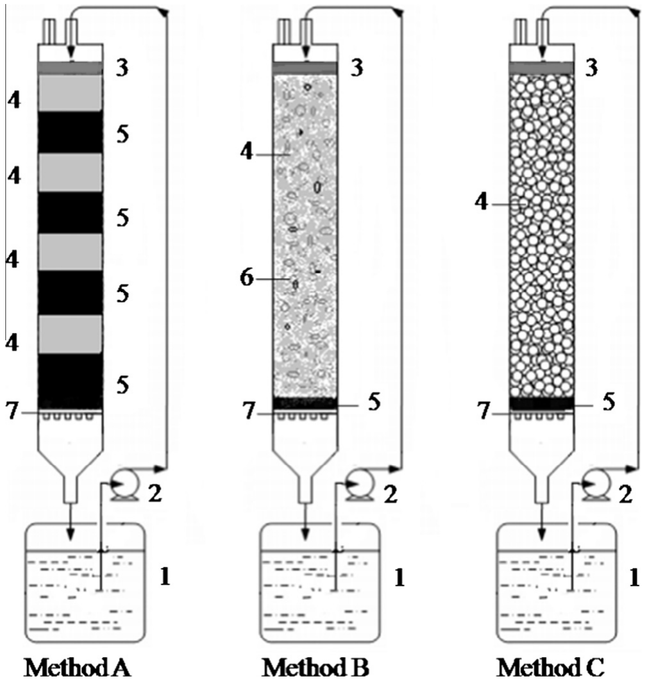

Fig. 1. Diagram of the column bioreactor in three potential heap construction methods of flotation tailings. 1, glass container; 2, peristaltic pump; 3, sterile sponge; 4, flotation tailings; 5, quartz sand; 6, Yulong mineral; 7, support plate.

2.2.1. Layered heap construction method (Method A)

The tailings were mixed with 10% (v/v) H_2SO_4 solution adequately, and the liquid ratio (v/w) was 20%. 5 cm thickness quartz sand sized at 2.5–5 mm was loaded at the bottom of the column, then 5 cm thickness tailings mixed with H_2SO_4 solution were placed on the surface of the quartz sand. Then quartz sand and tailings were loaded in accordance with this order. Finally, four alternating layers of quartz sand and tailings were used in the column, respectively (Fig. 1).

2.2.2. Agglomerate heap construction method (Method B)

The tailings blended fully with Yulong mineral sized at 2.5–5 mm, and the ratio of tailings and Yulong mineral was 2:1 (w/w). The mixed ores were mixed with 10% (v/v) H_2SO_4 solution and the liquid ratio (v/w) was 20% as well. Then agglomerate ores were loaded into the column (Fig. 1).

2.2.3. Pelletized sintering heap construction method (Method C)

The tailings added with 1.5% (w/w) bentonit were placed into an agglomeration drum. The drum was turned at 20 rpm with 5° inclination while deionized water as binder was sprayed onto the ores for 20 min. The deionized water was applied with a spray bottle at a dosage of 0.15 mL/g ores. After the agglomeration process completed, the agglomerates were removed from the drum and passed through the 6–8 mm screen. The agglomerates were air dried at 60 °C for 4 h, then placed into the muffle remaining 800 °C for 10 min. Parts of agglomerates were cooling and submersed completely into a H_2SO_4 solution (pH 1.5) for 24 h to test the integrity of agglomerates.

In Method B and C, a layer of support quartz sand sized at 2.5–5 mm was placed 20 mm thickness at the bottom of the columns. In each heap construction method, approximate 1.3 kg weight tailings were loaded into columns. Finally, a piece of sterile sponge was placed on the top surface of each column to ensure the uniform wetting of the ores (Fig. 1).

2.3. Mixed microorganisms culture

Pregnant leaching solution (PLS) and leaching slags were collected from the Dexing Copper Mine in Jiangxi, China. The microorganisms in PLS were harvested by centrifuging at 12,000 rpm for 15 min. The leaching slags were washed with pH 2.0 sterilized deionized water, and the supernatant was centrifuged as well as PLS. The microorganisms from PLS and slag surfaces were gained and then inoculated into the pH 2.0 culture medium at 30 °C for the enrichment of initial inoculum. The composition of culture medium was 3 g/L $(NH_4)_2SO_4$; 0.5 g/L $MgSO_4{\cdot}7H_2O$; 0.1 g/L KCl; 0.5 g/L K_2HPO_4; 0.01 g/L $Ca(NO_3)_2$. In addition, $FeSO_4{\cdot}7H_2O$ (44.7 g/L), S (10 g/L) and tailings (2%, w/v) were added as energy sources. Finally, microorganisms were harvested when the cell density reached 1×10^8 to 2×10^8 cells/mL and then washed with pH 2.0 culture medium, which resulted in the initial inoculum.